

**(19) World Intellectual Property Organization
International Bureau**



(43) International Publication Date
6 June 2002 (06.06.2002)

(10) International Publication Number
WO 02/44709 A2

PCT

- (51) **International Patent Classification⁷:** G01N 29/00 (81) **Designated States (*national*):** AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(21) **International Application Number:** PCT/US01/51194

(22) **International Filing Date:** 12 November 2001 (12.11.2001)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:** 09/727,130 29 November 2000 (29.11.2000) US

(71) **Applicant:** COOPER CAMERON CORPORATION [US/US]; 515 Post Oak Boulevard, Suite 1200, Houston, TX 77027 (US).

(72) **Inventors:** KNIGHT, Ray; 11245 West Road, Apt. 128A, Houston, TX 77065-4830 (US). WELLS, Jim; 12419 Rosehill Lane, Houston, TX 77070 (US).

(74) **Agent:** COOK, Tim; Bracewell & Patterson, L.L.P., P.O. Box 61389, Houston, Tx 77208-1389 (US).

(84) **Designated States (*regional*):** ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

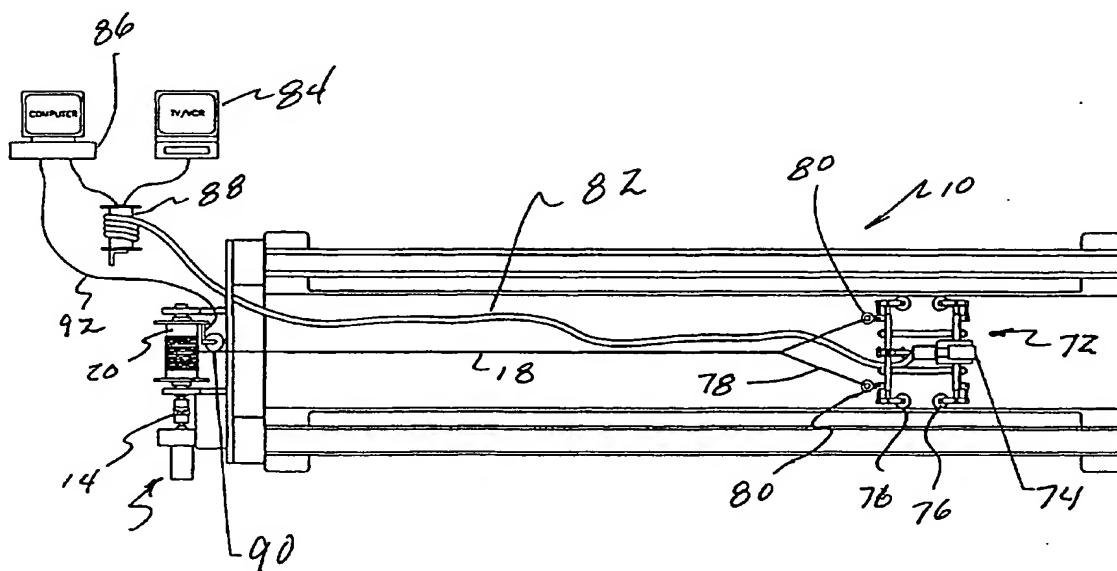
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: ULTRASONIC TESTING SYSTEM



(57) Abstract: A comprehensive system for the cleaning, inspection, and testing of tubulars, particularly riser pipes, is provided. In a first aspect, a method of inspecting a tubular comprises cleaning, visually inspecting, corrosion mapping, and TOFD testing the tubular. In another aspect, a specially designed or adapted tool is provided for each of the steps of the method.

ULTRASONIC TESTING SYSTEM

FIELD OF THE INVENTION

The present invention relates generally to the field of non-destructive testing and, more particularly, to a method and apparatus for cleaning and inspecting tubulars, including inspecting for flaws in pipe sequentially using pulse echo and time of flight diffraction (TOFD).

BACKGROUND OF THE INVENTION

There has long been a need for methods of cleaning and inspecting tubulars, particularly offshore riser pipe, on site. Typical methods used today include disassembling the riser pipe from a rig, transporting the riser pipe to a yard, and there conducting inspection and testing of the tubular using well known techniques. Such a method is not only expensive and time consuming, but also very disruptive of normal operations on the rig.

Thus, there remain a need for a system and method of inspecting tubulars on site to minimize down time of the rig, and to save the costs of transporting and returning the tubulars under inspection.

Even the techniques used at the yard for the testing and inspection of tubulars have certain drawbacks. Various techniques have been developed to detect flaws in structures, particularly welds in such structures. The ability to detect flaws in structures such as tubulars in drilling and production rigs and pipelines is especially critical before any catastrophic failure occurs.

Ultrasonic testing of metal structures has proved to an effective and practical tool for nondestructive testing (NDT). Known ultrasonic techniques typically yield reliable examination results. However, some geometries make known ultrasonic techniques difficult or even impossible to apply, or yield inaccurate results.

1 One technique that has gained common acceptance in the NDT field is
2 referred to as the echodynamic technique. This technique consists of measuring the
3 duration of the defect echo in axial or circumferential tube direction when the
4 ultrasonic probe (in pulse-echo mode) is moved over the defect. Such a defect may
5 involve slag, porosity, stress cracking, or other anomalies from the anticipated metal
6 grain structure. In the pulse-echo mode, the depth of a defect is calculated from the
7 probe displacement distance at which a defect echo was picked up. To detect the
8 defect, the amplitude of the defect echo should be above noise level. However, many
9 defects that are of particular concern escape detection if they are oriented in a
10 particular way relative to the applied pulse echo, because this technique relies on the
11 reflectivity of the defect. In fact, the pulse echo technique is used in the present
12 invention for corrosion mapping in determining pipe wall thickness. However, as
13 previously described, the pulse echo technique may miss certain flaws, and this fact
14 has lead to the development of other testing techniques.

15 The Time of Flight Diffraction technique (TOFD) was developed by the
16 AEA's Harwell Laboratory in Britain in the mid seventies as a method of accurately
17 sizing and monitoring the through-wall height of in-service flaws in the nuclear
18 industry. For weld inspection, it was quickly recognized that the method was equally
19 effective for the detection of flaws, irrespective of type or orientation of the flaw,
20 since TOFD does not rely on the reflectivity of the flaw. Rather, TOFD detects the
21 diffracted sound initiating from the tips of the flaw.

22 In TOFD, a transmitting probe emits a short burst of sound energy into a
23 material and the sound energy spreads out and propagates in an angular beam. Some
24 of the energy is reflected from the flaw but some of the energy is incident to the flaw
25 and is diffracted away from the flaw. A fraction of this diffracted sound travels
26 toward a receiving probe. The diffracted signals which are received by the receiving
27 probe are time resolved using simple geometry calculations and are graphically
28 displayed in a grey scale form.

1 While the TOFD technique has proved effective for many geometries, there
2 remains a need for a method and system for detection of flaws from within a
3 cylindrical structure, such as a pipe or riser stanchion. The present invention is
4 believed to be the first structure and method of NDT using TOFD from within a
5 tubular such as a riser pipe.

6 SUMMARY OF THE INVENTION

7 The present invention addresses these and other needs in the non-destructive
8 testing art by providing a comprehensive system for the cleaning, inspection, and
9 testing of tubulars, particularly riser pipes. In a first aspect of the present invention,
10 a method of inspecting a tubular comprises cleaning, visually inspecting, corrosion
11 mapping, and TOFD testing the tubular. The present invention is also adapted for use
12 with new construction in which the cleaning step may not be necessary in some cases.
13 In another aspect of the invention, a specially designed or adapted tool is provided
14 for each of the steps of the method.

15 The step of cleaning the inside of the tubular includes pre-wetting, if desired,
16 to remove loose debris and to soften dried drilling fluids and other materials. An air
17 motor driven wire brush with an alignment tool is then pulled or pushed through the
18 tubular. For small lines, which may include weld material protruding into the
19 cylindrical space, a cutting tool is also provided to precede the wire brush. The wire
20 brush may also be followed by a jet spray of water to wash away cuttings, rust, and
21 dust.

22 The step of visual inspection comprises moving a camera throughout the
23 tubular. A digital linear placement transducer, referred to as an encoder, is provided
24 to precisely locate the camera within the tubular. The camera provides a video signal
25 to a computer and to a recorder for a permanent record.

26 The step of corrosion mapping employs a pulse echo system to map wall
27 thickness of the tubular. A drive system is provided to move the tool holding the
28 pulse echo probes through the tubular, and the computer once again makes a record

1 of the mapping. Finally, a TOFD system is provided to detect flaws in the tubular
2 seam and girth welds, such as in-service defects, stress and fatigue cracking,
3 corrosion, erosion, weld fabrication defects, lack of fusion (LOF), slag porosity, and
4 other defects.

5 These and other features of the invention will be apparent to those skilled in
6 the art from a review of the following description along with the accompanying
7 drawings.

8 BRIEF DESCRIPTION OF THE DRAWINGS

9 Figure 1a is a side view in partial section of a cleaning system in accordance
10 with this invention for cleaning a large ID pipe, such as a 21" ID main riser pipe.

11 Figure 1b is an end view of the cleaning system of Figure 1a.

12 Figure 2 is a side view in partial section of a cleaning system for cleaning
13 smaller ID pipe, such as 3" and 4" pipes.

14 Figure 3a is a side view in partial section of a system for the visual inspection
15 of the larger diameter pipe.

16 Figure 3b is an end view of the visual inspection system of Figure 3a.

17 Figure 4a is a side view in partial section of a system for the visual inspection
18 of small ID pipe, such as for a 3" or 4" nominal ID pipe.

19 Figure 4b is an end view of the visual inspection system of Figure 4a.

20 Figure 5a is a side view in partial section of a system for performing corrosion
21 mapping inspection of a large diameter pipe.

22 Figure 5b is an end view of the system of Figure 5a.

23 Figure 5c is a side section view of corrosion mapping tool suitable for use in
24 the inspection system of Figures 5a and 5b.

25 Figure 6a is a side view in partial section of a system for performing corrosion
26 mapping inspection of a small diameter tubular.

27 Figure 6b is an end view of the system of Figure 6a.

Figures 6c and 6d are side section views of corrosion mapping tools for 3" and 4" nominal ID tubulars, respectively, suitable for use in the system of Figures 6a and 6b.

Figure 7 is a side view in partial section of a preferred system for performing TOFD testing of a large diameter pipe.

Figure 8a is a side view in partial section of a preferred system for performing TOFD testing of a small diameter tubular.

Figures 8b and 8c are side section views of TOFD tools for performing testing of 4" and 3" tubulars, respectively, suitable for use with the system of Figure 8a.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention includes a system for the inspection of tubulars and a method of conducting such an inspection using the system. The system of the invention includes the systems for carrying out the various stages of inspection, as well as the tools which have been designed or specially adapted for the inspection. The method of the invention comprises primarily four steps: (1) cleaning; (2) visual inspection; (3) corrosion mapping; and (4) TOFD inspection. The following description follows through the four steps of the method, with the structure described during each step.

Cleaning

Figures 1 and 1a show the arrangement for cleaning the main, 21" ID riser pipe 10. At one end of the pipe 10 is coupled a winch assembly 12 driven by a winch motor 14 and the winch assembly 12 is adapted for mounting to a flange 16 of the pipe 10. A wire line 18 is wound on a winch spool 20, enough wire line to reach the entire length of the pipe 10. The end of the wire line 18 terminates in a swivel 22, which couples to a cleaning tool 24. As used herein, the term "drawing system" refers to the mechanism for drawing the cleaning tool through the pipe, and includes the winch assembly 12, the winch motor 14, and the wire line 18.

1 On the opposite end of the pipe 10 is mounted a drive mechanism 26 to
2 actuate the cleaning tool 24. The drive mechanism 26 includes a motor mount 28 on
3 which is mounted an air motor 30. The motor mount 28 also includes at least two
4 guide bars 32 which slidably extend into auxiliary lines 34 and the guide bars are
5 preferably about 3.5 feet long. The air motor 30 is provided with an air supply 36,
6 which may be any available air supply of about 120 psi. Coupled to the drive shaft
7 of the air motor is a drive tube 38, which is preferably made up of 3' sections, and the
8 sections of drive tube 38 may be quickly and easily made up with couplings 40. The
9 end of the drive arm or tube 38 opposite the drive motor 30 is coupled to the cleaning
10 tool 24. The cleaning tool 24 includes a pair of wire brushes 42 and 44, separated by
11 a centralizer ring 46, which maintains the cleaning tool in alignment within the pipe
12 10 to ensure complete circumferential cleaning of the inside of the pipe. Finally,
13 speed control for the air motor 30 is provided by an air regulator and dryer 48 for
14 complete control of the cleaning operation.

15 To begin the procedure of cleaning the inside of the main pipe 10, the inside
16 of the pipe is first flushed, preferably with potable water, to remove loose debris and
17 to pre-wet any dried drilling mud for ease of removal by the cleaning tool 24. Next,
18 the motor mount 28 is installed by sliding the guide bars into the auxiliary tubes.
19 With the guide bars fully inserted, the position of the air motor can be adjusted to
20 center the axis of rotation of the motor output shaft to account for variations in the
21 positioning of the auxiliary pipes. The mounting assembly is then pulled back out
22 (about 3.5 feet), and the first section of drive tube 38 is installed on the motor drive.
23 This provides sufficient clearance for the cleaning tool 24 on the end of the first
24 section of drive tube 38. The cleaning tool is then placed inside the end of the main
25 pipe 10. Next, the air line 36 is connected to the motor and the air regulator 48 is
26 adjusted to zero. The air pressure is then slowly increased until the cleaning tool 24
27 just starts to turn. Note that due to the coefficient of friction, more air pressure will
28 be required to start turning the tool than is required to keep the tool turning.

1 The cleaning tool can then be manually run into the pipe for cleaning the first
2 portion. Alternatively, the wire line 18 can be pushed through the pipe 10 and
3 connected to the swivel 22 prior to making up the tool to the air motor. With this
4 setup, the winch motor is used to pull the cleaning tool through the pipe. When the
5 motor mount 28 contacts the end of the pipe, the air supply 36 is shut off, and the
6 mount 28 is pulled back to provide enough clearance to attached another 3' section
7 of drive tube 38. The procedure is repeated until the entire length of the pipe 10 has
8 been cleaned with the cleaning tool. The process is completed by flushing the pipe
9 with water until the water at the other end of the pipe is clear of debris.

10 Another setup is required for cleaning the smaller auxiliary pipes. Figure 2
11 depicts the arrangement for cleaning such smaller diameter 3 and 4 inch nominal ID
12 pipes, which may otherwise be referred to herein as tubulars or lines. These are, for
13 example, a choke and kill line 50 and a mud booster line 52, respectively. A similar
14 arrangement is used for cleaning both lines, and the cleaning tool comprises a cutting
15 or grinding tool 54 which is used primarily to remove welds which extend down into
16 the lines 50 and 52. Removing the protruding welds ensures that the inspection tools
17 which are later to be used have room to travel freely through the pipes.

18 Immediately behind the cutting tool 54 is a wire brush 56 for removing rust
19 and loose debris from the inside of the pipe. Immediately behind the wire brush 56
20 is a centralizing sleeve 58, preferably made of a hard plastic or other appropriate
21 material, to align the cutting tool 54 and the wire brush 56. The cutting tool, wire
22 brush, and centralizing sleeve are all coaxially mounted to a drive shaft 60 which is
23 coupled to an air motor 62 for high speed rotation of the coaxially mounted tools.
24 The air motor 62 is provided with pressurized air from a rig air supply line 64 which
25 is provided with a valve 66 which provides both positive shutoff and speed control
26 by controlling air pressure to the air motor 62. On a common line with the rig air
27 supply line 64 is a water supply line 68 which provides water under pressure to water
28 jet nozzle 70 which washes rust, dust, and other debris forward through the pipe.

Visual Inspection

Figures 3a and 3b depict a structure for visual inspection of the interior surface of the main pipe 10. An alternative means for visual inspection uses a camera mounted on a TOFD tool, described below.

The structure of Figure 3a includes a camera carrier 72 on which is mounted a camera 74 having a wide angle lens for complete circumferential viewing of the interior of the pipe. The carrier 72 is retained securely centered within the pipe 10 with a plurality of spring loaded wheels 76. The carrier with camera mounted thereon is drawn through the pipe with a harness 78 coupled to the carrier with swivel mounts 80. The harness 78 is joined to the wire line 18 wound onto the winch 20 spool, as previously described.

The camera 74 provides a signal over a signal line 82 to a television and video cassette recorder 84 and a computer 86 to provide real time viewing of the camera view and to provide a record of the visual inspection. The signal line 82 is preferably taken up on a take-up reel 88 to keep the slack out of the signal line 82 during the inspection. As the wire line 18 is taken up by the winch, it passes through a digital linear placement transducer or encoder 90, which is simply an idler of precisely known diameter so that the position of the carrier 72 along the longitudinal direction of the tubular is known. The encoder 90 is coupled to the computer 86 by a signal line 92. The encoder may alternatively be mounted to the carrier 72, and the signal line 92 may then be included with the signal line 82.

Because of constricted space, a different structure is called for when viewing the interior surface of the smaller lines 34, as depicted in Figures 4a and 4b. A similar arrangement is provided for the inspection of both 3" and 4" lines. The system of Figures 4a and 4b uses the same mounting for the winch as previously described, but now it can be seen that the winch is rotatable on its mount so that the wire line 18 may be directed onto a line 34.

The camera 74 is mounted to a centralizer sleeve 94, which is coupled to the wire line 18 with a swivel mount 96. The centralizer sleeve adapts the same camera

1 to different ID auxiliary lines. The signal from the camera 74 is provided over the
2 signal line 82 to the television and recorder 84 and to the computer 86 as previously
3 described. The camera is drawn through the auxiliary line 34 by the wire line, which
4 passes over the encoder 90 so that the longitudinal position of the camera is known
5 at all times. The wire line passes over an idler pulley 98 which presses against the
6 encoder 90.

7 The purpose of the visual inspection of the interior surface is to show up any
8 obvious surface cracks or corrosion, and to provide for a more comprehensive
9 ultrasonic inspection to follow. It provides the user with a visual inspection record,
10 through the recorder 84, of the assembled drilling riser joint internal pipe surfaces,
11 for example, although the system and method of this invention may be applicable to
12 other tubulars.

13 To use the visual inspection system, the camera is installed to the appropriate
14 size adapter sleeve for the line to be inspected, and the camera cable is fished through
15 the line, starting from the box end to the pin end, for example. The cable is then
16 connected to the camera, and the winch assembly is mounted to the end of the riser
17 pipe. The wire line is coupled to the encoder, and the remaining cable connections
18 are made to the computer and television with recorder. The encoder is zeroed, and
19 the image is viewed on the screen of the television to ensure adequate picture quality.
20 Then, using the winch, the wire line is drawn through the tubular. The user can
21 watch the television while making an inspection record. The procedure should then
22 be repeated for all tubulars to be inspected.

23 *Corrosion Mapping*

24 Figures 5a, 5b, and 5c depict the structure for corrosion mapping of the
25 interior of the main pipe 10. Figure 5a is a side view of a corrosion mapping tool
26 100, constructed in accordance with the invention, positioned within the main pipe
27 10. Figure 5b is an end view showing the mounting hardware for moving the tool
28 100, and Figure 5c is a detail view of the corrosion mapping tool 100 itself.

Referring first to Figure 5c and the corrosion mapping tool 100, the tool comprises primarily a truncated cylinder 102 with flanges 104 and 106 at the left and right ends of the cylinder 102, respectively. The cylinder 102 is axially oriented along an axis 103, which when in use is coaxial with the axis of the pipe 10. Mounted to the flange 104 in abutting contact is a seal plate 108 which is retained by an end plate 110, held to the flange with a set of bolts 112, for example. One such bolt 112 may be replaced by a lifting eye 114 to assist in transporting the tool 100, since the tool 100 is roughly 20" in diameter and quite heavy. At the other end of the cylinder 102, mounted to the flange 106, is an end plate 116, a seal plate 118, and a backing support ring 120, all held to the flange 106 with a set of bolts 112, for example.

Note that the mounting hardware for the seal plates 108 and 118 is not the same for each seal plate. The end plate 110 is to the left of the seal plate 108, *i.e.* away from the flange 104, and the end plate 116 is to the left of the seal plate 118, *i.e.* in abutting contact with the flange 106. This arrangement provides support for the compliant seal plates when the bend under friction against in the inside diameter of the pipe 110 when the tool 100 is drawn through the pipe.

The end plate 116 also provides a mount for a hub 122 held to the end plate 116 with a plurality of bolts 124, for example. The hub receives a coupling 126, which receives a water hose connection 128 (see Figure 5a). Water from the water hose connection 128 provides a couplant for the pulse echo signal used in the corrosion mapping as described below. The hub 122 also includes a water channel 130 leading the flow of water to a flexible tube 132 which carries the water to a penetration 134 through the cylinder 102. Thus, the water floods an annular chamber 135 (See Figure 5a) formed by the cylinder 102, the seal plates 108 and 118, and the interior diameter of the main pipe 10.

The end plate 110 provides a mount for a cable connector 136 which receives a transducer signal cable 138 (See also Figure 5a) to be described below. The transducer signal cable 138 terminates in a pulse echo transducer 140, which is

1 mounted in an insert **142** which in turn is installed in the cylinder **102**. It should be
2 understood that although only one transducer is shown, a plurality of transducers are
3 used in order to provide a full 360° coverage to map the entire pipe. The transducer
4 **140** provides a pulse echo signal to determine wall thickness of the cylinder **102** in
5 a manner well known in the art. The cylinder **102** may also be provided with a nipple
6 **144** to receive a lifting ring, if desired.

7 Figures 5a and 5b show the arrangement for the use of the tool **100**. As
8 previously described with regard to the cleaning of the pipe **10**, the winch assembly
9 **12** is mounted at one end of the pipe **10** and the winch assembly is mounted to the
10 flange **16**. The winch is driven by a winch motor **14** and includes a winch spool **20**
11 upon which is wound a wire line **18**, enough wire line to reach the entire length of the
12 pipe **10**. The end of the wire line **18** terminates in a harness **146**, which couples to
13 the tool **100** with a set of swivels **148**.

14 The transducer **140** provides a signal over the signal line **138** (which may be
15 the same signal line **82** as previously described) to the computer **86** to provide a
16 record of the corrosion mapping inspection. The signal line **82** is preferably taken up
17 on the take-up reel **88** to keep the slack out of the signal line **82** during the inspection.
18 As the wire line **18** is taken up by the winch, it passes through the encoder **90** as
19 before. The encoder provides position of the tool **100** along the longitudinal direction
20 of the main pipe **10**. The encoder **90** is coupled to the computer **86** by the signal line
21 **92**. The encoder may alternatively be mounted to the carrier **100**, and the signal line
22 **92** may then be included with the signal line **82**.

23 To use the tool **100**, the wire line **18** and the signal line **138** are fed through
24 the length of the pipe **10**. The winch assembly **12** is then mounted to the flange **16**
25 and the tool is hooked up to the signal line **138** and the connecting hose **128**. The
26 tool **100** is placed flush with the end of the pipe **10**, and the encoder is zeroed. Water
27 is then applied through the hose connection **128**, filling the annular chamber **135**.
28 The winch motor is then turned on, pulling the tool **100** the entire length of the pipe
29 **10** and the position of the tool **100** is known at all times from the encoder. The

1 transducer provides a measurement of wall thickness of the entire pipe 10, which is
2 recorder by the computer 86 for later review and analysis.

3 A similar arrangement is used for the corrosion mapping of the smaller
4 tubulars, as shown in Figures 6a, 6b, 6c, and 6d. Referring first to Figures 6c and 6d,
5 and preferred tool for corrosion mapping of the 3" and 4" tubulars are shown. A tool
6 150 is adapted for use in 4" nominal ID tubulars, and a tool 152 is adapted for use in
7 3" nominal ID tubulars. The tools contain the same components, which are numbers
8 the same in Figures 6c and 6c. Thus, the following detailed description applied to
9 both tools.

10 The tool (either 150 or 152) comprises primarily a cylindrical body 154, a left
11 end cap 156, and a right end cap 158. A seal retaining ring 160 is mounted to the left
12 end cap 156 with a set of bolts 162, for example, and a seal retaining ring 164 is
13 mounted to the right end cap 158 with a set of bolts 166. for example. The seal
14 retaining ring 160 holds a seal plate 168 in place, and similarly the seal retaining ring
15 164 holds a seal plate 170 in place. The seal retaining rings 160 and 164 are
16 preferably secured to their respective retaining rings by a set of bolts 172.

17 The right end cap 158 provides a mount for a nipple 174 and a hose connector
18 176, providing a connection for the water source or hose connection 128. When
19 pressurized, water flows through the nipple 174 into a set of flow channels 178 to
20 flood the chamber formed by the seal rings, the cylindrical body, and the wall of the
21 tubular. This provides a signal couplant for the pulse echo for the corrosion mapping
22 tool.

23 The left end cap 156 provides a mount for a two ring 180 to provide a means
24 for pulling the tool through the tubular. The left end cap 156 includes penetrations
25 182 through which pass signal cables 184 to carry the ultrasonic test signal from the
26 tool. The signal cables 184 terminate at transducers 186, which are mounted in
27 penetrations through the cylindrical body 154. It should be understood that enough
28 transducers are provided for a complete 360° coverage around the circumference of
29 the tubular.

1 Figures 6a and 6b illustrate the use of the tool. The system of Figures 6a uses
2 the same mounting for the winch as previously described, and the winch is rotatable
3 on its mount so that the wire line 18 may be directed onto the tubular 34. The tool
4 100 is drawn through the tubular 34 by the wire line, which passes over the encoder
5 90 so that the longitudinal position of the tool 100 is known at all times. The wire
6 line passes over an idler pulley 98 which presses against the encoder 90.

7 To use the corrosion mapping tool 100, the wire line 18 and the signal cable
8 138 are fed down through the tubular 34 to the end, where the tool 100 is attached.
9 The tool is then coupled to the wire line and signal cable, and the hose connection
10 128 is attached. The tool is registered with the end of the tubular, and the encoder is
11 zeroed. With water pressure supplied by the hose connection 128 to provide a
12 couplant for the transducers, the tool is drawn all the way through the tubular,
13 measuring wall thickness and providing measurements to the computer.

14 *Time of Flight Diffraction Inspection*

15 The tool for performing Time of Flight Diffraction (TOFD) is not described
16 in detail, because the tool may be acquired from ScanTech, 1212 Alpine Suite A,
17 Longview Texas 75606. Further, the TOFD technology itself was adapted from
18 techniques provided by AEA Technology plc, whose registered office is at 329
19 Harwell, Didcot, Oxfordshire OX11 0RA, United Kingdom. The technique will be
20 described in sufficient detail for a complete understanding of the present invention.

21 In summary, the TOFD scanner system includes a very maneuverable crawler
22 unit with four, large diameter rare earth magnetic wheels. The magnetic wheels grip
23 the interior surface of the pipe 10 so that the crawler can be guided the entire length
24 of the pipe. The crawler is remotely steered by the user, and the wheels include
25 surface conforming suspension. The crawler is motor driven, and the motor is
26 preferably a water shielded, high-torque, rare earth electric motor. All wiring,
27 including control signals and inspection signal cables are shielded. The encoder,
28 previously described, is preferably enclosed within the crawler for precise position

1 measurement and indication. The TOFD transducers are double-gimbaled for a full
2 range of motion.

3 Figure 7 shows a crawler **200** carrying the TOFD system in operation. Two
4 such crawlers **200** are shown in Figure 7, in order to show inspection of a
5 longitudinal weld **202** and a girth weld **204**, while the system preferably includes a
6 single crawler. The crawler preferably includes a single umbilical **206**, which
7 includes a bi-directional signal cable **208** and a water supply line **210**. As previously
8 described, the water supply line **210** provides the water couplant for the TOFD
9 transducers. The signal cable **208** is preferably taken up on the take-up reel **88** to
10 keep the slack out of the signal cable **208** during the inspection.

11 The signal cable includes a number of lines, including a video signal line **212**
12 from the on-board camera to the television and video cassette recorder **84** and the
13 computer **86** to provide real time viewing of the camera view and to provide a record
14 of the inspection. The signal cable **208** further includes a signal line **214** from the
15 encoder for precise position measurement and indication, a signal line **216** for
16 carrying the TOFD signal to the computer, and a maneuvering control signal line **218**
17 from a remote, joystick control **220**.

18 In operation, the crawler **200** is driven down the pipe, and the operator views
19 the interior of the pipe at the television monitor **84**, controlling the movement of the
20 crawler with the joystick control **220**. When a girth weld **204** is encountered, the
21 crawler is turned and driven around the circumference of the pipe.

22 Figure 8a depicts the arrangement for the performance of TOFD testing in
23 smaller tubulars in accordance with this invention. Figures 8b and 8c depict the tools
24 of the invention for conducting TOFD testing in 4" and 3" nominal ID tubulars,
25 respectively. The tools are identical, with the exception of an adapter sleeve **230** to
26 adapt the tool to the larger 4" ID tubular. Thus, the following description will apply
27 to both Figures 8b and 8c.

28 A TOFD tool **232** comprises a body **234**, a left end cover **236**, and a right end
29 cover **238**. Within the body is a carrier and slide assembly **240**, which provides a

1 cam action for a set of yokes 242. The yokes support a set of shoes 244 in which are
2 mounted the TOFD transducers 246. The shoes 244 are shown in Figures 8b and 8b
3 in the deployed position in order for the shoes to make contact with the interior
4 surface of the small tubular in preparation for the TOFD test. The carrier and slide
5 assembly 240 is moved transversely by air pressure from an air cylinder 248 which
6 is supplied from a nipple 250 and air connection 252. Actuation or retraction of a rod
7 254 from the air cylinder moves the carrier and slide assembly 240 back and forth,
8 so that the yokes ride up and down on the slides, deploying and retracting the shoes.

9 The body also retains a connector 256 for a water connection. The water from
10 the water connection, as previously described, serves as a couplant for the TOFD
11 signal. The body is firmly connected to a drive arm 258 which provides a means for
12 rotating the tool 232 in a rotary motion for complete circumferential coverage of the
13 TOFD test. The drive arm 258 is preferably connected to a square tube drive means
14 260 (Figure 8a) by removable screws 262. At the opposite end of the body is a signal
15 cable connector 264 for connecting the tool to the computer, preferably by way of a
16 pre-amplifier 266 (Figure 8a). At the same end of the body is an eyebolt connection
17 268 for pulling the tool through the tubular.

18 Figure 8a shows the use of the tool 232 in a small diameter tubular in
19 performing the TOFD test. As previously described with regard to the use of other
20 tools, the wire line 18 is coupled to the eyebolt 268 and then back to the winch
21 assembly 12 driven by a winch motor 14 and the winch assembly 12 is adapted for
22 mounting to the flange 16. The wire line 18 is pulled over an idler pulley 98 which
23 contacts the encoder 90 to precisely locate the tool 232 within the tubular. The signal
24 cable 264 is wound to a takeup reel 88 to keep slack out of the cable. At the other
25 end of the tubular are provided the drive means 260, a water supply connection 270
26 for the water couplant, and an air supply connection 272 for coupling to the
27 connection 252 (Figures 8b and 8c).

28 To use the tool 232, the signal line 264 and the wire line 18 are fed through
29 the tubular and connected to the tool. The air and water connections are made up,

1 and rotating drive means 260 is connected. Then, the tool is registered with the end
2 of the tubular, and the encoder is zeroed. The tool is the pulled through the tubular
3 and rotated by the rotating drive means 260, imaging the tubular for internal flaws.
4 The computer captures the image for later review and analysis.

5 The principles, preferred embodiment, and mode of operation of the present
6 invention have been described in the foregoing specification. This invention is not
7 to be construed as limited to the particular forms disclosed, since these are regarded
8 as illustrative rather than restrictive. Moreover, variations and changes may be made
9 by those skilled in the art without departing from the spirit of the invention.

We claim:

1. A method of inspecting a pipe comprising the steps of:
 - a. visually inspecting the inside of a pipe with a camera;
 - b. determining wall thickness of the pipe with a corrosion mapping tool from inside the pipe; and
 - c. inspecting the pipe for flaws with a time of flight diffraction tool from inside the pipe.

2. The method of claim 1, further comprising the step of cleaning the inside of the pipe prior to inspecting the inside of the pipe with a camera.

3. The method of claim 2, wherein the step of cleaning the inside of the pipe includes grinding the inside of the pipe to remove weld material that extends into the pipe to a point inside the nominal ID of the pipe.

4. The method of claim 1, further comprising the steps of:
 - a. prior to the step of visually inspecting the inside of a pipe, coupling the camera to a drawing system;
 - b. prior to the step of determining wall thickness of the pipe with the corrosion mapping tool from inside the pipe, coupling the corrosion mapping tool to the same drawing system as in step a.; and
 - c. prior to the step of inspecting the pipe for flaws with the time of flight diffraction tool from inside the pipe, coupling the time of flight diffraction tool to the same drawing system as in step a.

5. A system for inspecting a tubular comprising:
 - a. an inspection tool; and

- 3 b. a drawing system coupled to the inspection tool with a wire
4 line, the drawing system adapted to pull the inspection tool
5 through the tubular.

1 6. The system of claim 5, further comprising a decoder to locate the
2 position of the inspection tool within the tubular.

1 7. The system of claim 5, wherein the inspection tool comprises a visual
2 inspection tool including a camera for visual inspection of the interior of the tubular.

8. The system of claim 5, wherein the tool comprises a corrosion
mapping tool.

1 9. The system of claim 5, wherein the tool comprises a time of flight
2 diffraction inspection tool.

1 10. The system of claim 5, further comprising a cleaning tool adapted to
2 be removably coupled to the drawing system.

1 11. The system of claim 5, wherein the tool is selected from the group
2 consisting of a corrosion mapping tool and a time of flight diffraction tool, each of
3 which is adapted to the coupled to the same drawing system.

1 12. The system of claim 10, wherein the cleaning tool comprises:
2 a. a wire brush;
3 b. a centralizer ring adjacent the wire brush;
4 c. a drive motor for driving the wire brush in a radial direction;
5 and

- 6 d. a drive arm coupled to the wire brush, the centralizer ring, and
7 the drive motor.

1 13. The system of claim 12, wherein the drive arm comprises a plurality
2 of sections adapted to be coupled together.

- 1 14. The system of claim 12, wherein the cleaning tool further comprises:
2 a. a mount on which the drive motor is mounted; and
3 b. at least two guide bars which slidingly extend into auxiliary
4 lines adjacent the pipe.

1 15. The system of claim 10, further comprising a rotary cutter adjacent the
2 wire brush.

- 1 16. The system of claim 7, wherein the visual inspection tool comprises:
2 a. a camera carrier to hold the camera, the camera carrier
3 adapted to be coupled to the wireline;
4 b. a plurality of spring loaded wheels to retain the carrier inside
5 the tubular; and
6 c. a signal line to couple the camera to a monitor.

- 1 17. The system of claim 7, wherein the visual inspection tool comprises:
2 a. a centralizer sleeve adapted to couple the camera to the
3 wireline; and
4 b. a signal line to couple the camera to a monitor.

- 1 18. The system of claim 8, wherein the corrosion mapping tool comprises:
2 a. a substantially cylindrical body defining mutually opposed
3 ends;

- b. a flange on each of the ends of the body;
- c. a substantially circular seal plate on each flange; and
- d. a pulse echo transducer on the body.

19. The system of claim 18, further comprising a hub on the end plate, the hub including a coupling adapted to receive a water hose connection.

20. The system of claim 19, further comprising:

- a. a water channel in the hub terminating at the coupling;
- b. a flexible tube in fluid communication with the water channel;

and

- c. a penetration through the body; wherein the flexible tube is in fluid communication with the penetration, and wherein the water channel, the flexible tube, and the penetration carry water to flood an annular chamber formed by the body, the seal plates, and the interior diameter of the tubular.

21. The system of claim 18, further comprising:

- a. a cable connector on one of the flanges to receive a signal from the transducer;
- b. a signal cable to connect the cable connector to a computer exterior the tubular.

22. The system of claim 9, wherein the time of flight diffraction tool comprises:

- a. a body;
- b. a left end cover;
- c. a right end cover;

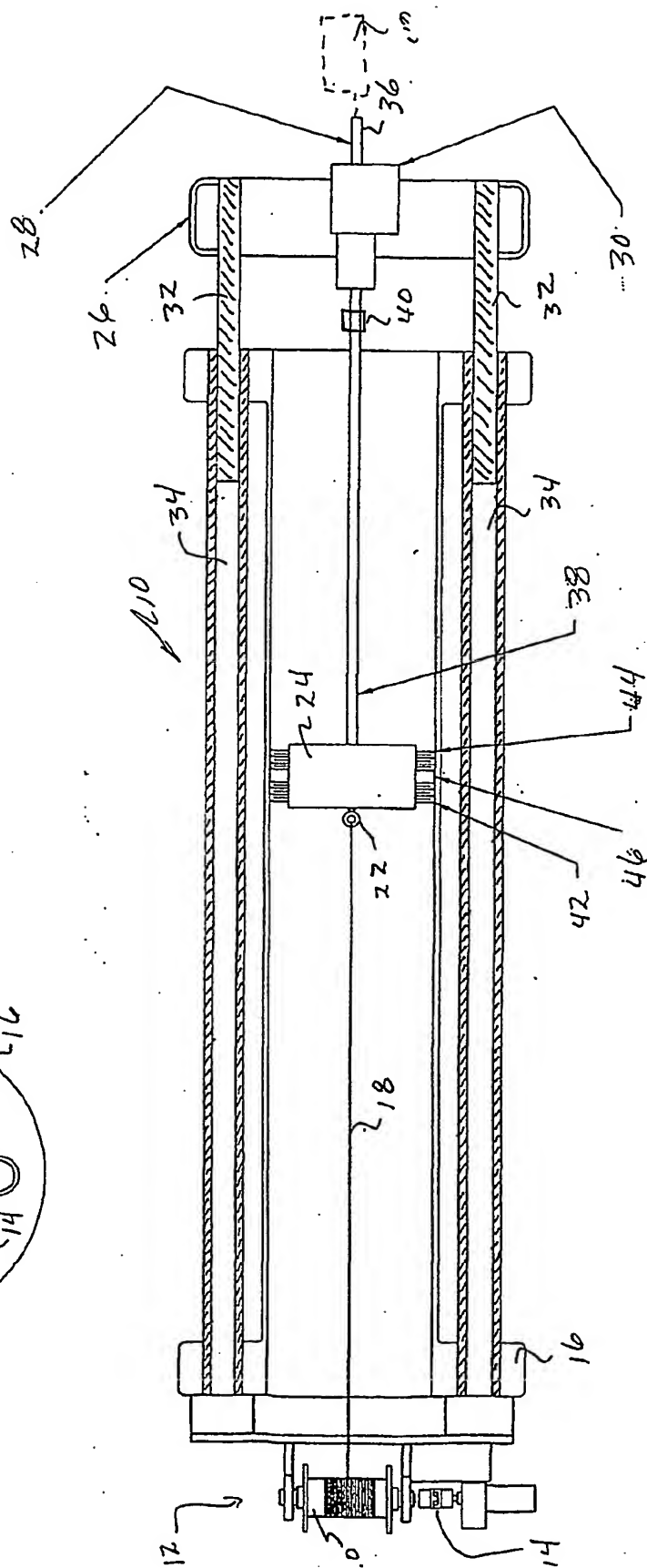
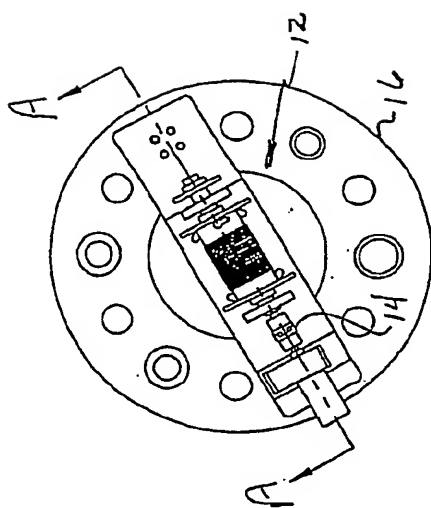
- 6 d. carrier and slide assembly within the body between the left
7 and right end covers, the carrier and slide assembly including
8 a cam surface;
9 e. a set of yokes riding on and actuated by the cam surface; and
10 f. a set of shoes, each shoes having a transducer mounted
11 therein.

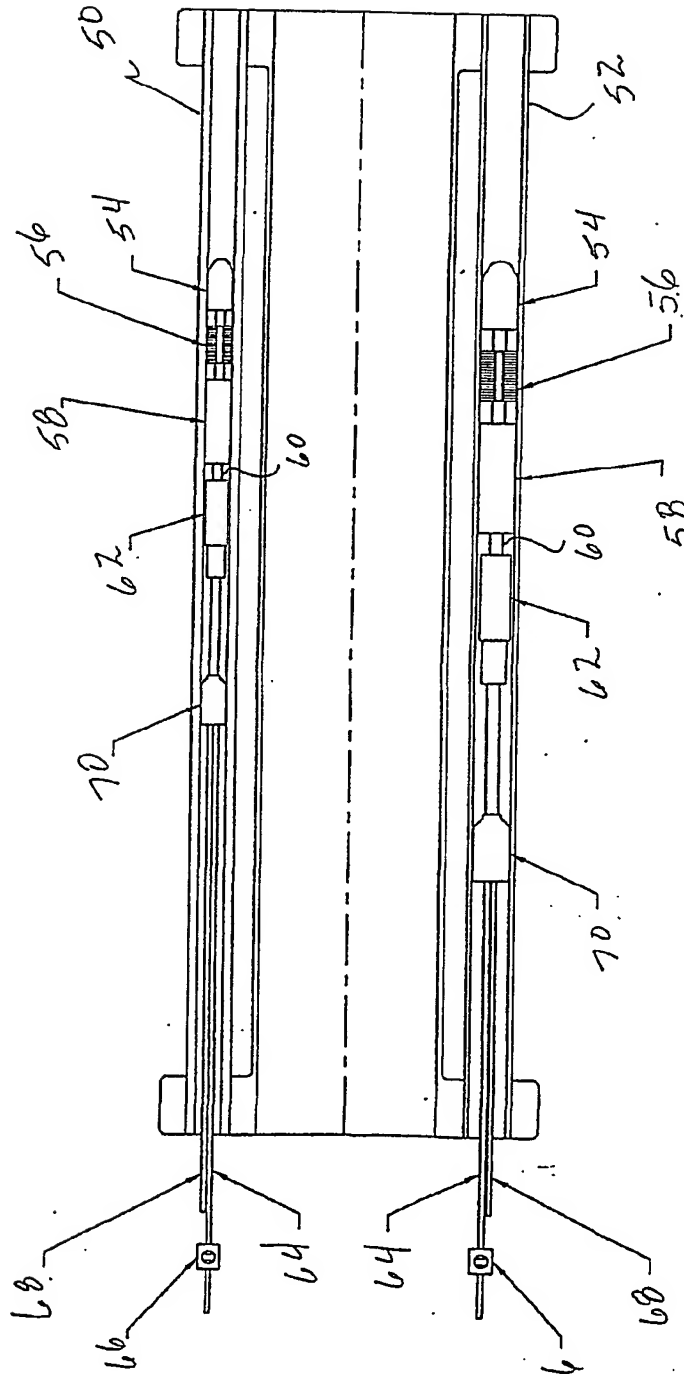
1 23. The system of claim 22, further comprising a pneumatic actuator
2 coupled to the carrier and slide assembly for linear movement of the cam surface.

1 24. The system of claim 22, further comprising a penetration through the
2 right end cover to receive a water couplant connection.

1 25. A time of flight diffraction tool comprising:

- 2 a. a self-powered, remotely operable crawler having a plurality
3 of magnetic wheels capable of holding the crawler in contact
4 with the interior surface of a tubular;
5 b. a time of flight diffraction transducer and receiver on the
6 crawler; and
7 c. an umbilical coupling the time of flight diffraction transducer
8 and receiver to a remote monitor.





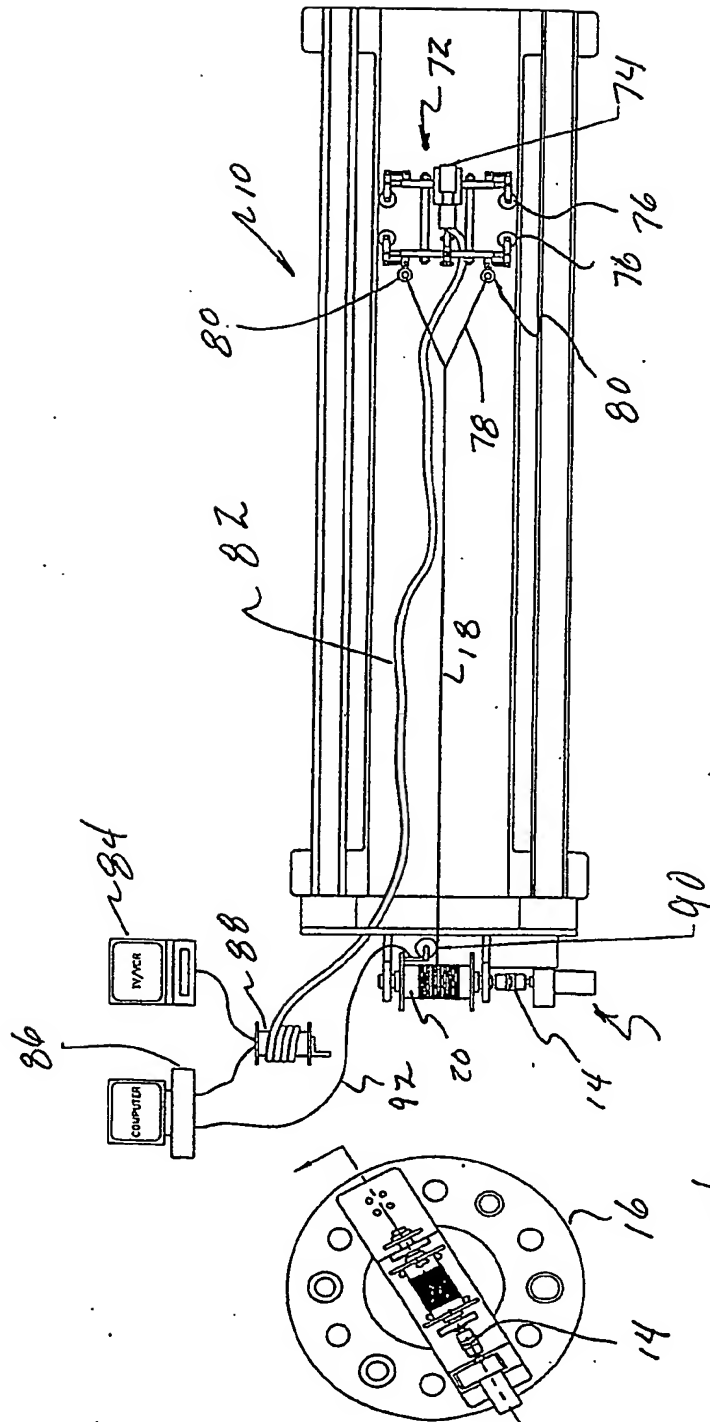
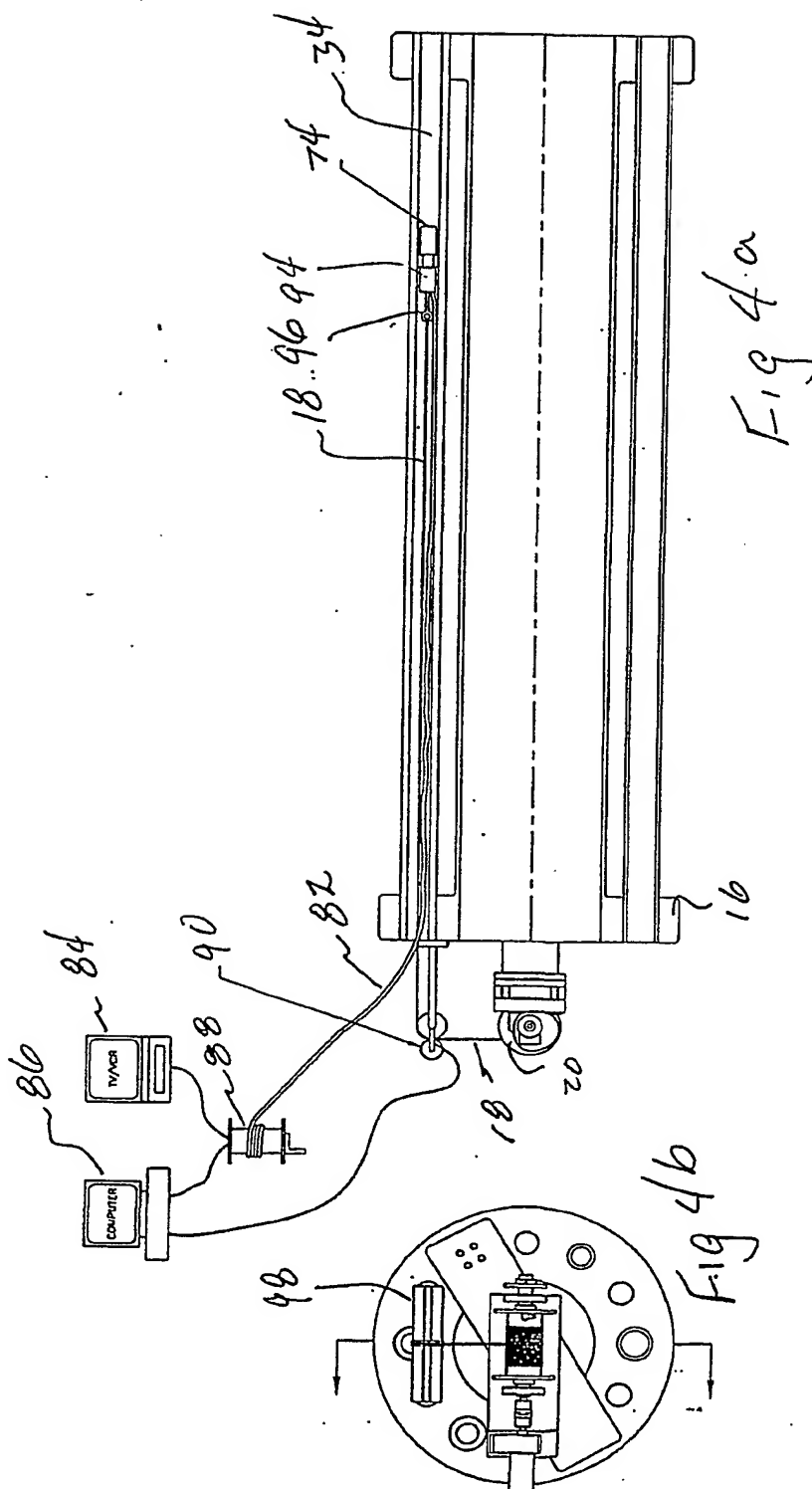
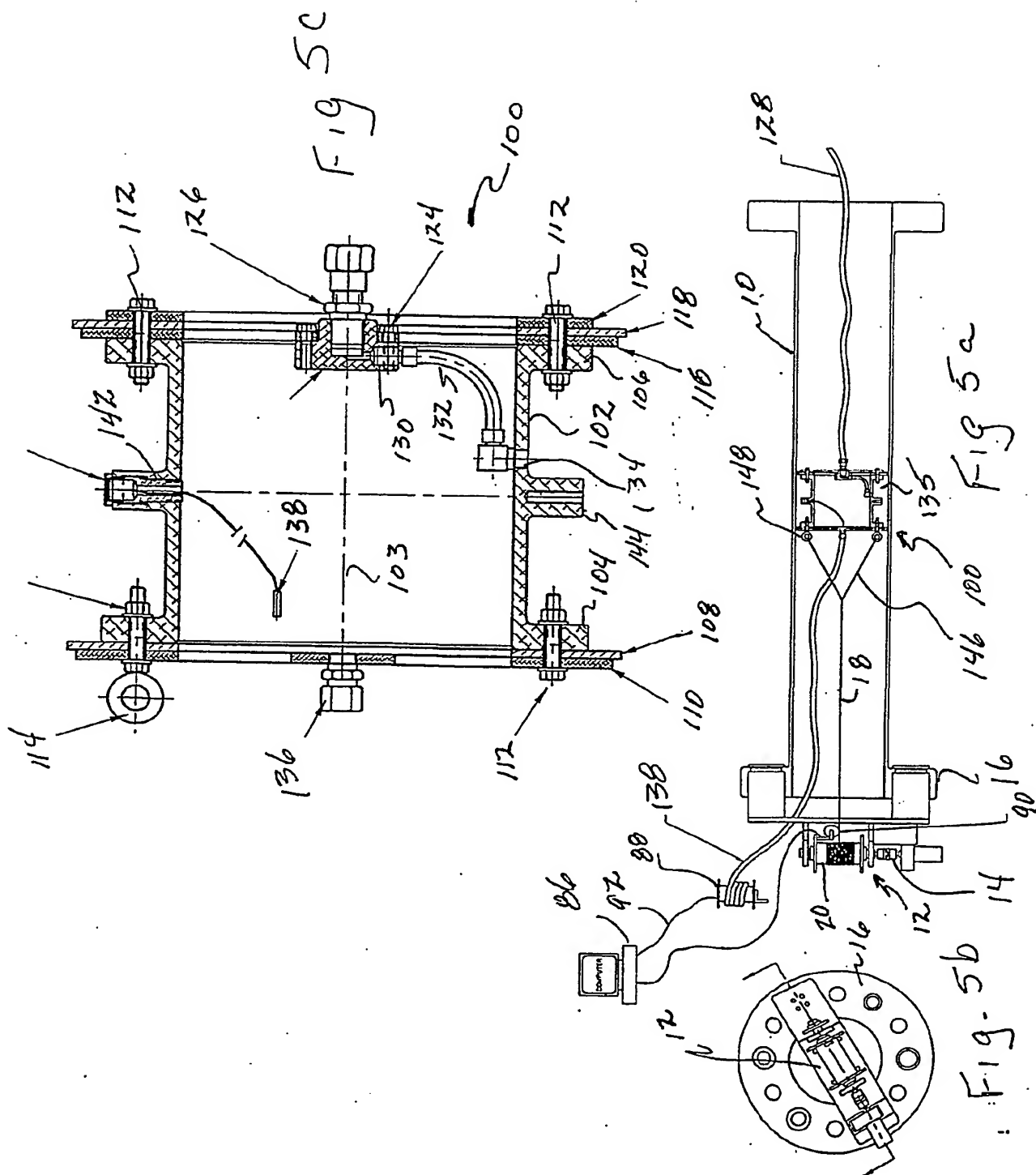
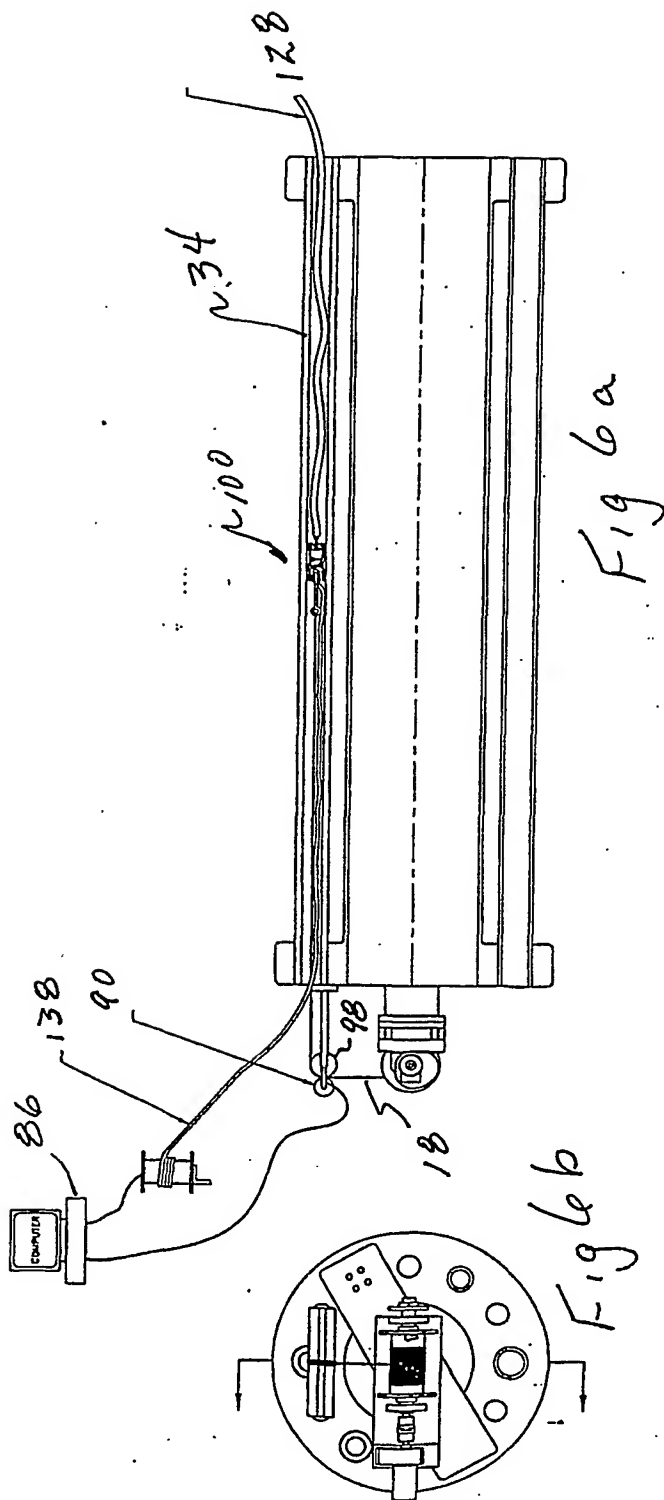


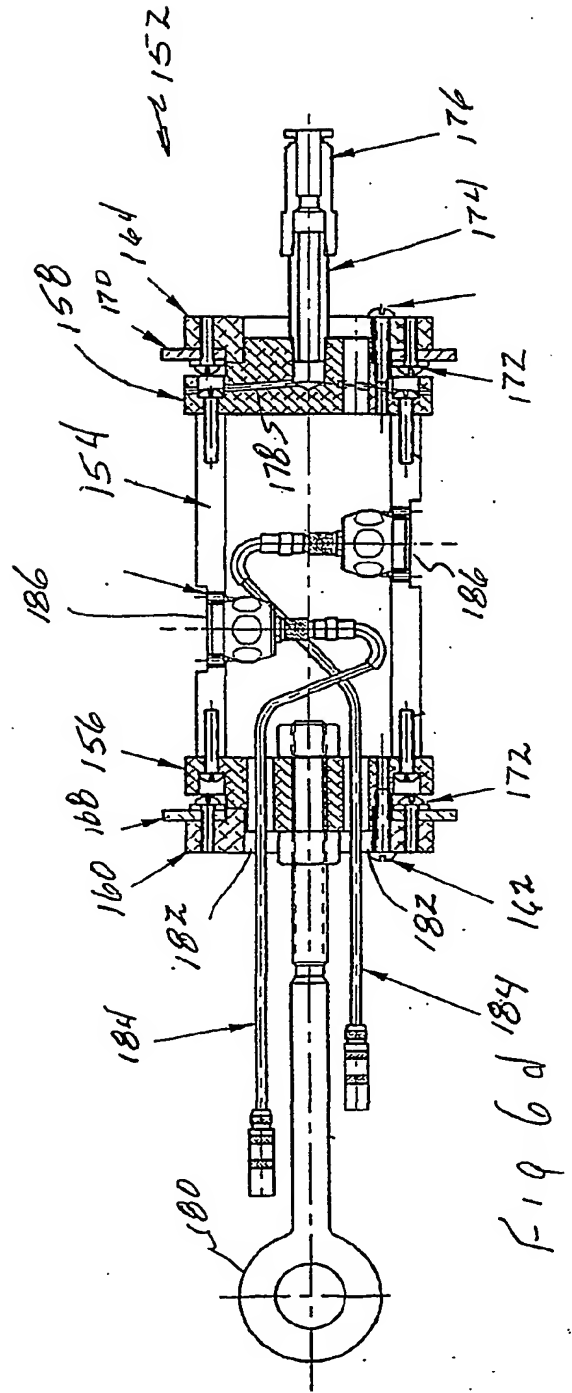
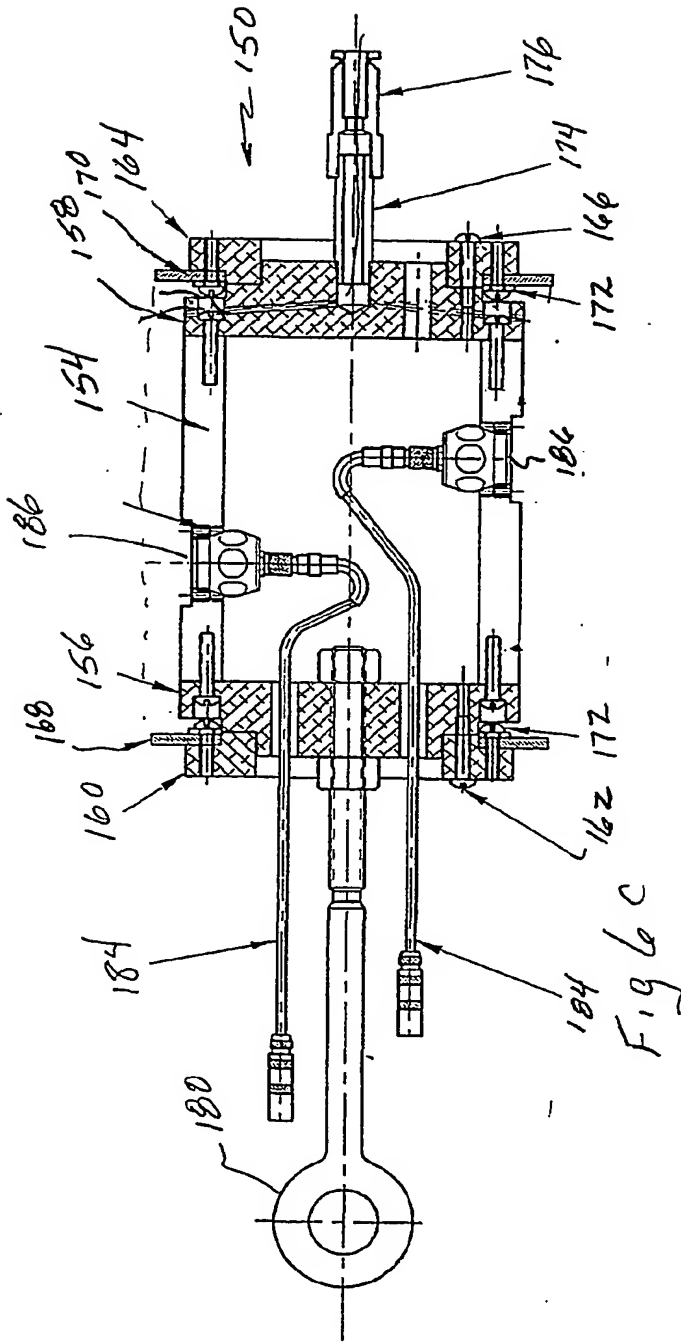
Fig. 3a

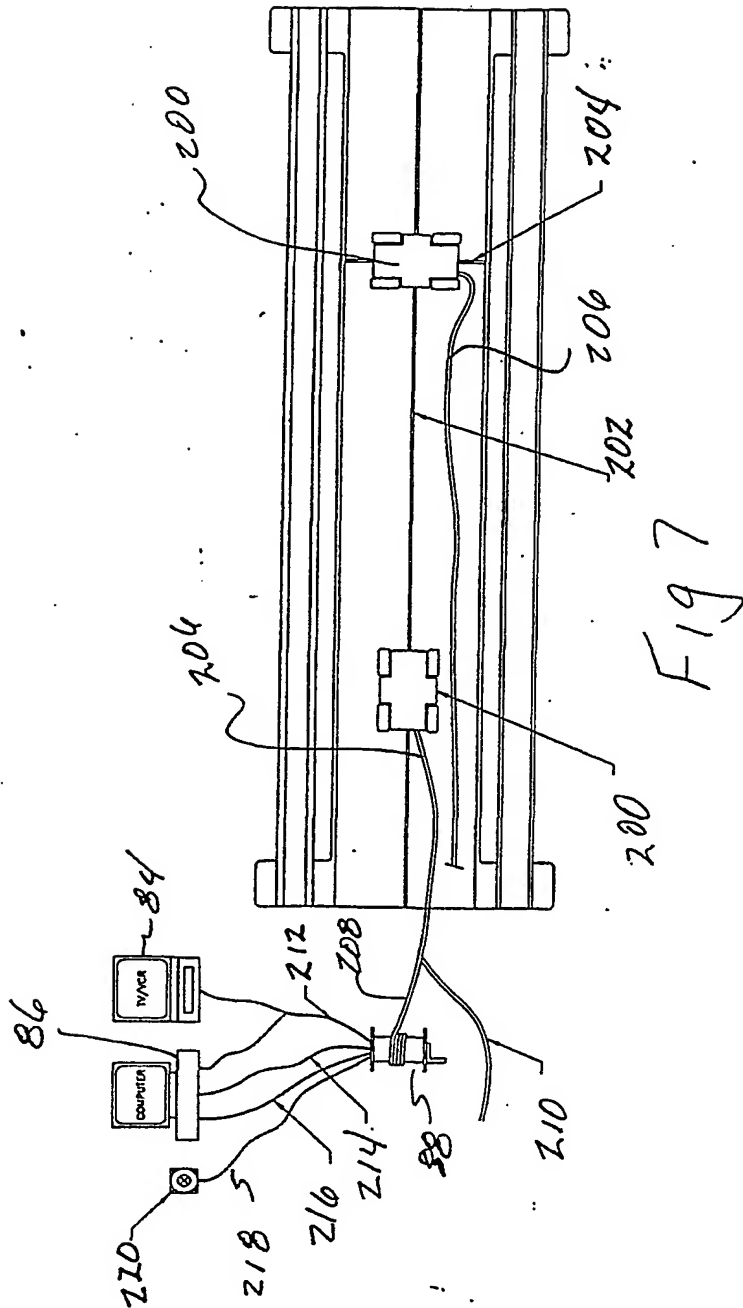
Fig 3b











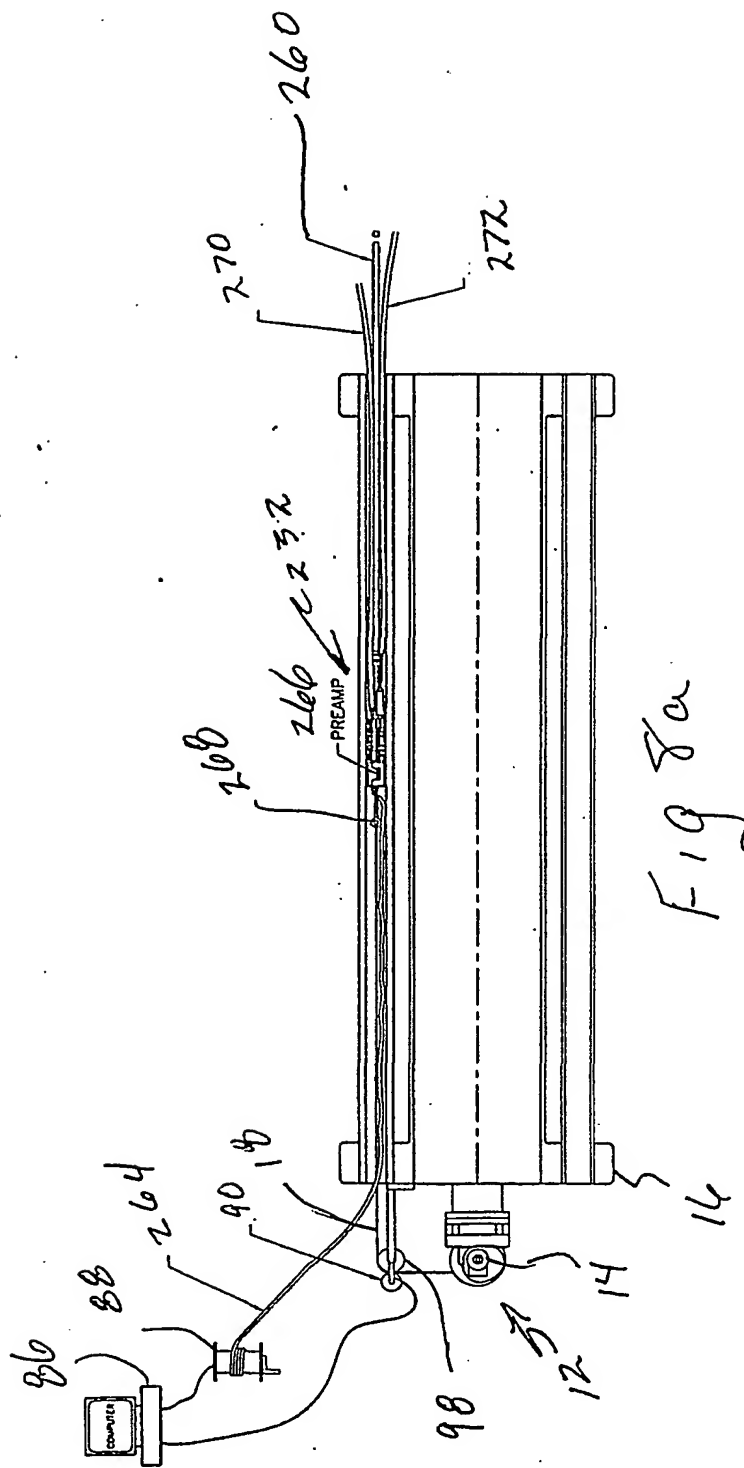
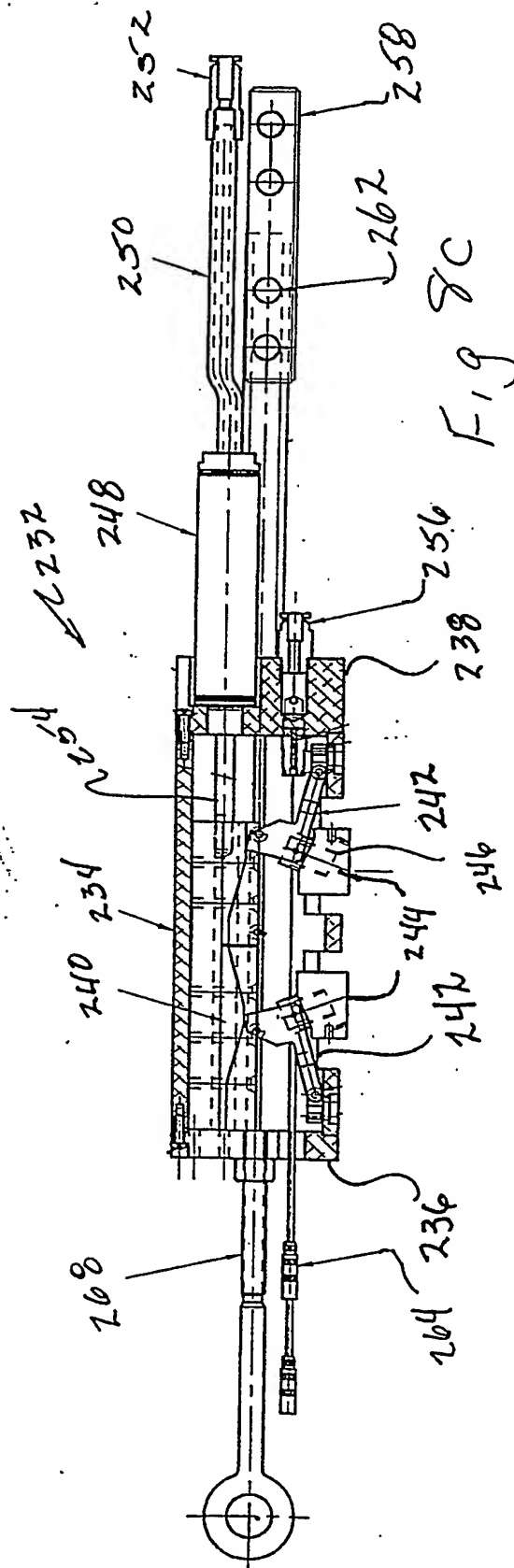
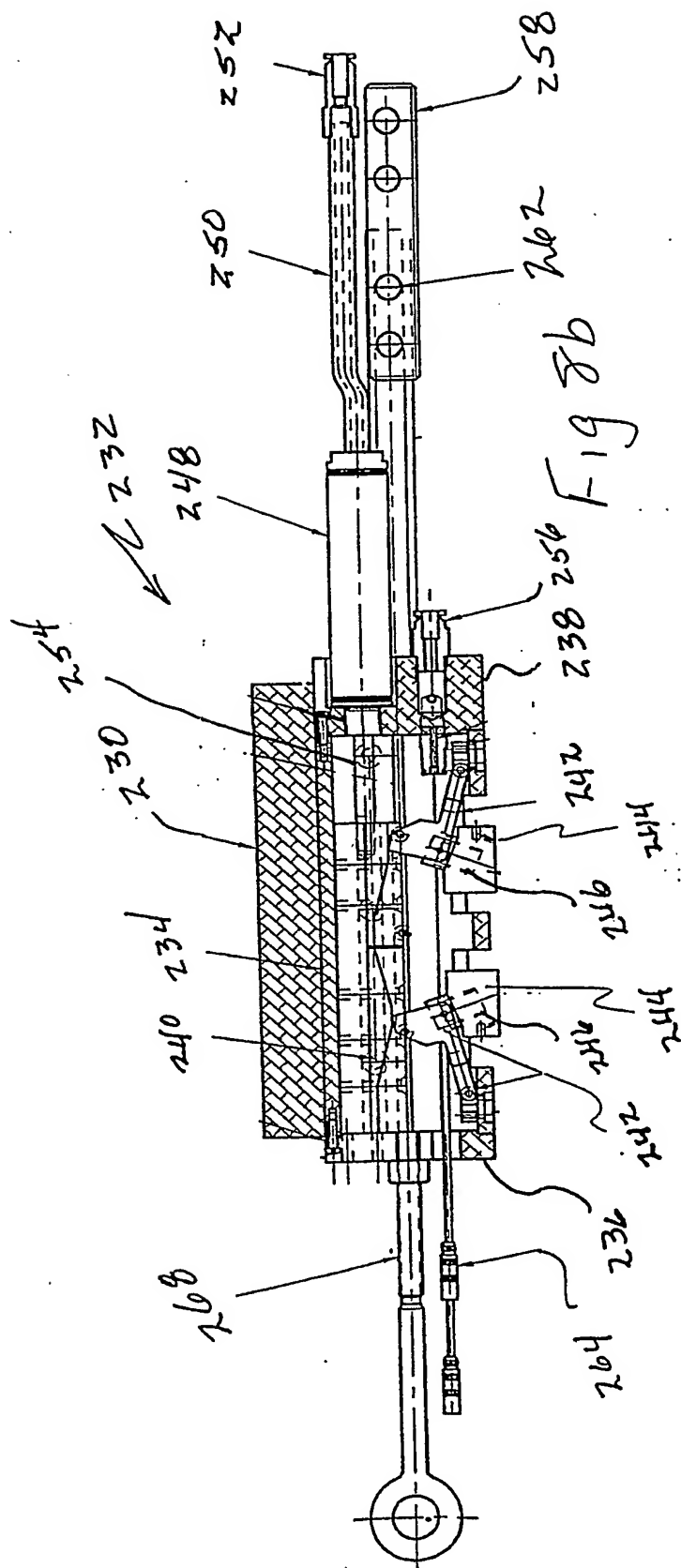


Fig 8a



(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
6 June 2002 (06.06.2002)

PCT

(10) International Publication Number
WO 02/044709 A3

(51) International Patent Classification⁷: **B08B 9/04**,
G01N 29/26

(21) International Application Number: PCT/US01/51194

(22) International Filing Date:
12 November 2001 (12.11.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/727,130 29 November 2000 (29.11.2000) US

(71) Applicant: **COOPER CAMERON CORPORATION**
[US/US]; 515 Post Oak Boulevard, Suite 1200, Houston,
TX 77027 (US).

(72) Inventors: **KNIGHT, Ray**; 11245 West Road, Apt. 128A,
Houston, TX 77065-4830 (US). **WELLS, Jim**; 12419
Rosehill Lane, Houston, TX 77070 (US).

(74) Agent: **COOK, Tim**; Browing Bushman P.C., 5718 Wes-
theimer, Suite 1800, Houston, TX 77057 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU,
AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU,

CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH,
GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC,
LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW,
MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG,
SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU,
ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM,
KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian
patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European
patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,
IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF,
CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD,
TG).

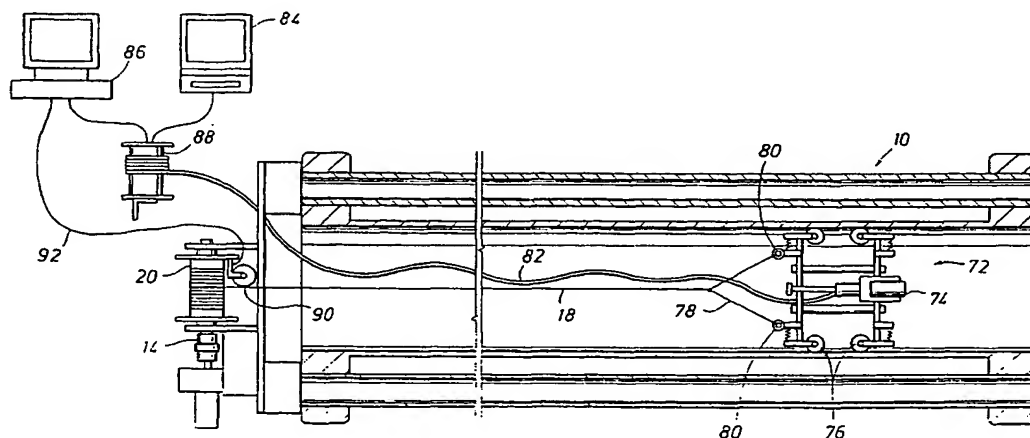
Published:

- with international search report
- before the expiration of the time limit for amending the
claims and to be republished in the event of receipt of
amendments

(88) Date of publication of the international search report:
14 August 2003

*For two-letter codes and other abbreviations, refer to the "Guid-
ance Notes on Codes and Abbreviations" appearing at the begin-
ning of each regular issue of the PCT Gazette.*

(54) Title: **ULTRASONIC TESTING SYSTEM FOR TUBULARS**



(57) Abstract: A comprehensive system for the cleaning, inspection, and testing of tubulars, particularly riser pipes, is provided. In a first aspect, a method of inspecting a tubular comprises cleaning, visually inspecting, corrosion mapping, and TOFD testing the tubular. In another aspect, a specially designed or adapted tool is provided for each of the steps of the method.



WO 02/044709 A3

INTERNATIONAL SEARCH REPORT

International Application No

/US 01/51194

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B08B9/04 G01N29/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 B08B G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	EP 0 736 722 A (BRITISH GAS PLC) 9 October 1996 (1996-10-09) abstract; figure 2 column 1, line 6 -column 3, line 45 ---	5 1-4,9, 11,22-25
X A	DE 198 37 032 A (ROHRABSPERRUNGEN UND HANDELSGE) 17 February 2000 (2000-02-17) column 1, line 33 - line 42 ---	5 1-4
X Y A	FR 2 667 519 A (INSPECTRONIC) 10 April 1992 (1992-04-10) abstract; claim 1; figure 1 column 1, line 1 -column 7, line 29 --- -/--	5 9,11 1-4, 22-25

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search

4 March 2003

Date of mailing of the international search report

05.06.03

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Uttenthaler, E

INTERNATIONAL SEARCH REPORT

International Application No

/US 01/51194

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	VAN AGTHOVEN R ET AL: "Ultrasonic inspection of risers: A simple and affordable alternative to self-contained pigging" PIPES PIPELINES INT;PIPES AND PIPELINES INTERNATIONAL SEPTEMBER/OCTOBER 2001, vol. 46, no. 5, September 2001 (2001-09), pages 37-44, XP009006658	1-4
A	the whole document	5,9,11, 22-25
Y	WO 95 03526 A (COMMW SCIENT IND RES ORG ;MELBOURNE WATER CORP (AU); MACINTYRE IAN) 2 February 1995 (1995-02-02)	1-4
A	abstract; figures 1,2 page 4, line 7 -page 20, line 11; table 1	5,9,11, 22-25
Y	US 5 473 953 A (APPEL D KEITH) 12 December 1995 (1995-12-12)	25
A	abstract; figure 1 column 1, line 7 - line 60	1-5
Y	BERNARD LARRY: "TIME-OF-FLIGHT DIFFRACTION TECHNOLOGY FOR ULTRASONIC INSPECTION OF PIPING AND PRESSURE-RETAINING COMPONENTS" MATER EVAL MAY 1987, vol. 45, no. 5, May 1987 (1987-05), pages 506-507, XP009006626	1-4,9, 11,25
A	the whole document	5,22-24
A	DE RAAD J A ET AL: "Mechanized ultrasonic testing on girth welds during pipeline construction" MATER EVAL;MATERIALS EVALUATION AUG 1997 AMERICAN SOC FOR NONDESTRUCTIVE TESTING, COLUMBUS, OH, USA, vol. 55, no. 8, August 1997 (1997-08), pages 890-895, XP009006892	1-4,9, 11,22-25
A	the whole document LILLEY J ET AL: "In-line inspection using time-of-flight diffraction" WELD MET FABR;WELDING AND METAL FABRICATION OCT 1991, vol. 59, no. 8, October 1991 (1991-10), XP009006661	1-4,9, 11,22-25
	the whole document	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 01/51194**Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)**

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-5, 9, 11, 22-25

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

1. Claims: 1-4, 5(part), 9, 11, 22-25

Apparatus and method for inspecting tubulars from the inside involving the time of flight diffraction technique.

2. Claims: 1 (part), 5(part), 7, 16, 17

Camera mounting and connecting on a tool for the visual inside inspection of a tubular, the tool being drawn through the tubular.

3. Claims: 1(part), 5(part), 6, 8, 11(part), 18-21

Corrosion mapping tool mounted on a tool for the inside inspection of a tubular, the tool being drawn through the tubular.

4. Claims: 1(part), 5(part), 10, 12-15

Cleaning tool removably mounted on a drawing system for the inside cleaning of a tubular, the cleaning tool being drawn through the tubular.

INTERNATIONAL SEARCH REPORT

Information on patent family members

Application No

US 01/51194

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0736722 A	09-10-1996	GB 2301646 A	11-12-1996
		DE 69601434 D	11-03-1999
		DE 69601434 T	22-07-1999
		ES 2127605 T	16-04-1999
DE 19837032 A	17-02-2000	NONE	
FR 2667519 A	10-04-1992	NONE	
WO 9503526 A	02-02-1995	AU 7259994 A	20-02-1995
		EP 0710351 A	08-05-1996
		ZA 9405334 A	28-02-1995
US 5473953 A	12-12-1995	NONE	